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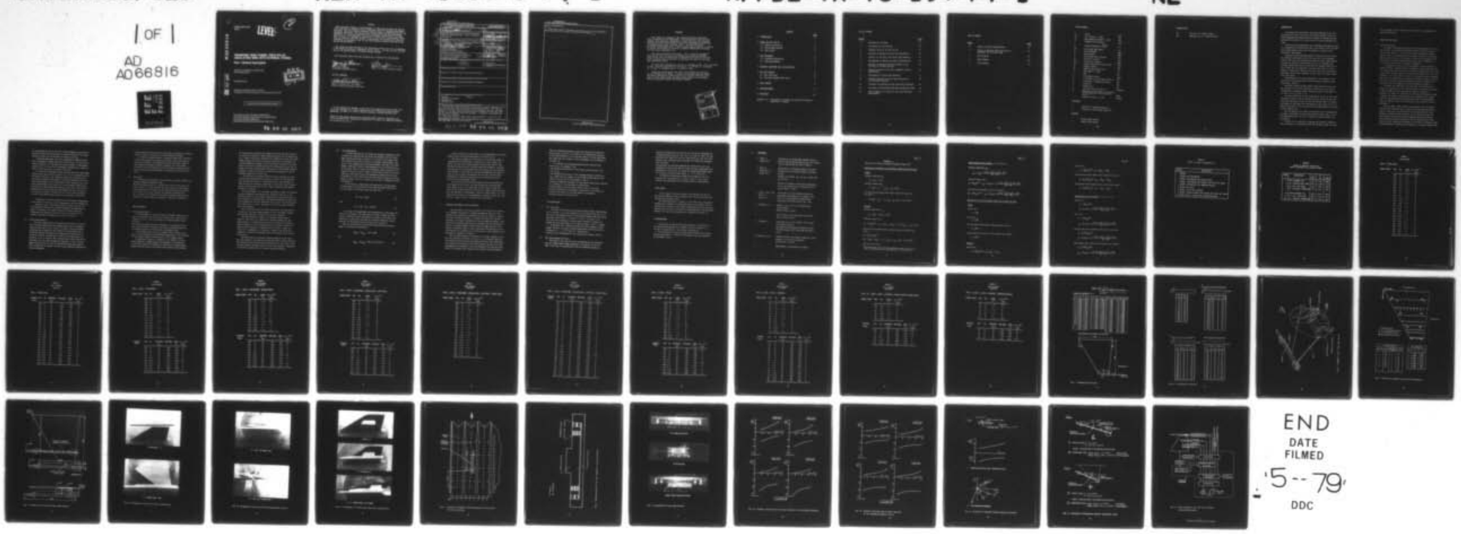

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TRANSONIC WIND TUNNEL TESTS ON AN OSCILLATING WING WITH EXTERNAL STORES

Part I. General Description

NATIONAL AEROSPACE LABORATORY
THE NETHERLANDS

DECEMBER 1978

TECHNICAL REPORT AFFDL-TR-78-194
Final Report for the Period February 1977 through December 1978

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AIR FORCE FLIGHT DYNAMICS LABORATORY
AIR FORCE WRIGHT AERONAUTICAL LABORATORIES
AIR FORCE SYSTEMS COMMAND
WRIGHT-PATTERSON AIR FORCE BASE, OHIO 45433

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James J. Olsen

JAMES J. OLSEN
Principal Scientist
Structural Integrity Branch

J. Olsen, for

PHILIP A. PARMLEY
Chief, Structural Integrity Branch

FOR THE COMMANDER

Ralph L Kuster Jr

RALPH L. KUSTER, JR., Col, USAF
Chief, Structural Mechanics Division

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A wind-tunnel investigation was carried out on an oscillating model of the F-5 wing with and without an external store (AIM-9J missile). The store was mounted at the wing tip as well as at a pylon underneath the wing. Detailed steady and unsteady pressure distributions were measured over the wing, while on the store aerodynamic loads were obtained. In addition, wind-tunnel wall pressures were recorded.

The tests covered the Mach number range between Ma = .6 and 1.35, and frequencies up to 40 Hz. over

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This report (part I) describes the general set-up of the experiments, while the parts II to IV give an analysis of the results.

FOREWORD

This report was prepared by the National Aerospace Laboratory (NLR) of Amsterdam, the Netherlands. The sponsors were the Air Force Armament Test Laboratory (AFATL/DLJ) of Eglin Air Force Base, Florida and the Air Force Flight Dynamics Laboratory (AFFDL/FBR and AFFDL/FBE) of Wright-Patterson Air Force Base, Ohio. The sponsorship was performed through AFOSR Grant 77-3233, administered by Captain D. Wilkins of the Air Force Office of Scientific Research (AFOSR/TKN) of Bolling Air Force Base, Washington D.C.

The report consists of four parts. Part I contains the general description; Part II discusses the steady and unsteady aerodynamic tests of the clean F-5 wing; Part III discusses the tests for the wing with tip-mounted stores; and Part IV discusses the tests for the wing with under-wing stores.

The principal investigators were Dr. H. Tijdeman and Mr. J.W.G. van Nunen of NLR. They were assisted by A. N. Kraan, A. J. Persoon, R. Poestkoke, Dr. R. Roos, P. Schippers and C. M. Siebert of NLR.

Within the United States Air Force, this program was initiated by Lovic Thomas of the AFATL. It would not have been possible without the expert assistance of Richard Wallace (Lt Colonel, USAF, Retired), and Lt Colonel Daniel Seger and Major Robert Powell of the European Office of Aerospace Research Development (EOARD).

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LIST OF SYMBOLS

C	chord	(m)
C_r	root chord; C_r = .6396	(m)
$\bar{C}$	mean geometric chord; $\bar{C}$ = .4183	(m)
F	frequency of oscillation	(Hz)
K	reduced frequency; $K = \frac{\pi F C_r}{V}$	(-)
Ma	free stream Mach number	(-)
M	pitching moment	(Nm)
N	yawing moment	(Nm)
P	free stream static pressure	(Pa)
P_o	stagnation pressure	(Pa)
P_{loc}	local static pressure	(Pa)
P_i	unsteady pressure at model surface	(Pa)
Q	dynamic pressure	(Pa)
Re	Reynolds number based on $\bar{C}$	(-)
S	semi span; S = .6226	(m)
t	time	(s)
V	free stream velocity	(m/s)
x	co-ordinate in free stream direction	(m)
y	co-ordinate in spanwise direction	(m)
Y	side force	(N)
Z	normal force	(N)
α	incidence; positive nose up	(degrees)
Θ	amplitude of oscillation in the section of accelerometers 1 and 2; positive nose up	(rad)
ω	angular velocity; $\omega = 2\pi F$	(rad/s)

SUBSCRIPTS

i	referring to unsteady quantities
q	referring to quasi-steady quantities

SUFFICES

+	denotes upper surface
-	denotes lower surface

ABBREVIATIONS

RE	real part of a complex number
IM	imaginary part of a complex number

1 INTRODUCTION

In October 1977 wind-tunnel tests were performed on an oscillating model of the F-5 wing with and without external store. The store represented an AIM-9J missile including its launcher and was successively mounted at the wing tip and at a pylon underneath the wing.

The aim of these experiments was to determine unsteady airloads on a representative fighter-type wing in the transonic and low supersonic speed regimes. Such data are necessary to support future theoretical developments.

During the tests detailed pressure distributions (both steady and unsteady) were measured over the wing, while the aerodynamic loads on the store were determined by means of strain gage balances. To study the effect of the external store on the unsteady wing loading (interference effect) as well as the unsteady loads on the store itself and its components, the model was tested in various stages of completeness. Starting with the clean wing, successively more parts of the store (launcher, missile body, aft wings, canard fins) were added.

Simultaneously with these measurements, the pressures on the tunnel wall were measured also, which may support studies on wall interference effects.

The tests covered the Mach number range between 0.6 and 1.35. The frequency of the pitch oscillation varied up to 40 Hz, which corresponds to a maximum reduced frequency (based on semi-span) of .4 at M = 0.6 to .2 at M = 1.35.

The final reporting of this investigation is done in four parts. The present report, part I, describes the test set-up and the test techniques and gives a survey of the test program. Part II contains the results of the clean wing configuration, while parts III and IV give similar data for the tip-store and the underwing-store configurations, respectively.

For the subsonic flow cases, the test data will be supplemented by results calculated with the Doublet-Lattice method (Ref. 1) and the NLRI-method (Ref. 2), which is suited to treat wing-body configurations.

Finally, it is noted that a complete set of data in tabulated form is gathered in a separate report NLR TR 78030 U (Ref. 3), while

also a magnetic tape, containing the test results is available for easy data handling.

2 MODEL AND TEST SET-UP

2.1 General description

The model investigated consisted of a wing equipped with a store. The wing was the slightly modified half model of the outer part of the F-5 wing (scale 1 : 4.5), used in earlier aeroelastic investigations (Ref. 4). The modification concerns a reduction of the model span, which was done for two reasons: to have the wing adapt the new store and to bring the already existing outer row of pressure orifices closer to the store (to study interference).

In streamwise direction the wing possesses a modified NACA 65-A-004.8 airfoil, characterized by a droopnose, which extends from the the leading edge towards the point of maximum thickness at 40 per cent of the chord. Further backwards the profile is symmetrical. The line of symmetry of this rear part is chosen as a reference for the incidence. Details of the planform and the airfoil are given in figure 1. During the clean wing tests the store attachment lips were covered with a fairing of which the geometric data are tabulated in figure 2.

The model was supported at the side wall of the test section (Fig. 3). Oscillations into a pitch mode about an axis at 50 per cent of the rootchord could be generated by means of a hydraulic actuator. To control the amplitude of oscillation and the mean steady incidence the actuator was equipped with a transducer. The actual motion of the model was monitored by eight built-in accelerometers (Fig. 4). Further details on the hydraulic test rig can be found in reference 5.

The wing model, made of Dural, was provided with 160 pressure orifices and connecting tubes, divided over eight spanwise sections (Fig. 4). Each section contained both at the upper and the lower surface 10 pressure points. Near the tip of the wing and near the pylon station, the position of the measuring sections was chosen such that more detailed information could be obtained about interference effects caused by the presence of the store. In addition eight miniature pressure transducers were mounted in the upper surface close

to the pressure points of section 2. These transducers were meant to provide the data for determining the transfer function of the tubes during the tests. No use was made of transition strips.

As already mentioned, the store represented an AIM-9J missile with corresponding launcher and pylon. The position of the store is shown in figure 5. It was tested in various stages of completeness (see Fig. 6). A listing of the different configurations is given in table 1. Pylon and store were made of Electron.

To obtain the aerodynamic loads acting on the store strain gage balances were used (see also section 2.2). In the configuration with the store at the tip a two component balance was installed at the interface of launcher and wingtip. This balance measured lift force and pitching moment. In the configuration with underwing store, two strain gage balances were used: one at the interface between wing and pylon, the other mounted between pylon and store. The first one measured the side force and the yawing moment acting on the pylon, the second one served to measure the lift force, pitching moment, side force and yawing moment acting on the launcher and missile.

In addition, to monitor the motion of the launcher independently of the motion of the wing, it was equipped with four accelerometers.

Finally, at some 75 positions along the slotted top wall of the wind-tunnel test section unsteady pressures were measured via tubes. To determine the transfer function of these tubes four transducers were mounted on the wall also. The location of the pressure orifices and transducers is given in figure 7.

2.2 Strain gage balances

The strain gage balances for measuring the loads on the store were specially designed for the present tests. They were manufactured of high quality steel (Armco 17-4-PH) by electro-discharge machining. Their dimensions were limited by the available space inside the launcher and pylon. The balances were machined out of one piece of steel and basically consist of two heavy parts connected by a set of springs. These springs deform under load and the deformations of the inner springs are measured by a set of strain gages (see also Fig. 8). The four component balance was provided with a double set of springs to obtain a good separation between the various components.

A sketch showing the principles of the design is presented in figure 8, while in figure 9 pictures of the three balances are shown.

To obtain a suitable balance concept, which means that differences in motion of wing and store should be minimal for all test frequencies, the stiffness of the balances had to be sufficiently high. In this respect the design was rather successful, since the dynamic calibration tests confirmed that the lowest natural frequency (pitch) of the launcher balances (provided with complete missile) was about 80 Hz.

2.3 Wind tunnel

The tests were performed in the transonic wind tunnel (HST) of the National Aerospace Laboratory (NLR).

This wind tunnel consists of a closed circuit with a test section of $1.60 \times 2.00\ m^2$. Top and bottom of the test section are slotted walls with an open ratio of 12 per cent. The velocity range of this tunnel is $0 \leq Ma \leq 1.35$ and by changing the stagnation pressure from $P_o = 12.5$ kPa to $P_o = 400$ kPa a wide range of Reynolds numbers can be covered. For further details the reader is referred to reference 6.

3 TEST PROCEDURES

3.1 Pressure measurements

The measurement of the mean steady and unsteady pressures on the model was performed with the help of pressure tubes, connecting the pressure orifices in the wing surface with scanning valves outside the model.

The electrical signals from the transducers in the scanning valves were measured and next reduced to the actual aerodynamic quantities at the model surface (for definitions, see appendix I.A).

In the steady case, this is a straight forward procedure. However, in the unsteady case the measured pressures have to be corrected for the dynamic response characteristics of the pressure tubes.

As described in detail in reference 7, the transfer of oscillatory pressures through pressure tubes depends on the dimensions of the tubing system, the frequency of oscillation, the mean steady pressure and the velocity of the main flow across the tube entrance.

For the present wing model the dimensions of each tube were taken to be identical, implying a common transfer function for all tubes which for a certain oscillation frequency will depend only on the local mean steady pressure and the flow velocity across the tube entrance. For a given stagnation pressure of the wind tunnel, the latter two parameters are directly related and thus can be replaced by only one. In practice the mean steady pressure has proven to be the most suitable parameter, since this quantity is measured simultaneously with the unsteady pressures at the orifice.

In principle, the transfer function can be obtained both theoretically and experimentally. However, in practice it has proven to work satisfactorily when it is determined for a limited number of tubes during the wind-tunnel experiment itself. This limited number should be chosen such that the full range of possible mean steady pressures is covered.

For this purpose, in the present experiment a number of miniature pressure transducers was mounted into the model (see Fig. 4). By positioning each of the pressure transducers as close as possible to the entrance of a pressure tube, the pressures measured by these miniature transducers could be regarded as the input to the related pressure tubes and so a direct calibration of the tubes under consideration was obtained.

By collecting the data for these tubes and by plotting them as a function of the mean steady pressure (or the local Mach number), the required calibration curves (Fig. 10) were obtained.

The data reduction procedure is indicated schematically in figure 11. The vector P_i, denoting the unsteady pressure at the model surface, is obtained from the vector P_u (being the unsteady pressure measured in the scanning valve) by a counter clockwise rotation φ and a reduction in magnitude with a factor α. Next, the vector P_i is decomposed in a component in phase (real part) and a component in quadrature (imaginary part) with respect to the motion of the model.

The mean steady and unsteady pressures measured at the tunnel wall are treated in the same way as described above, except that here the transfer function was determined theoretically. The level of the recorded unsteady pressures was too low for the pressure transducers in the wall to provide for an accurate enough calibration.

3.2 Load measurements

As mentioned earlier, the steady and unsteady aerodynamic loads acting on the launcher and the store were measured with the strain gage balances described in section 2.2. As far as the steady loads are concerned this could be done in a straight forward manner. However, in the unsteady case the balances measure the sum of the aerodynamic loads and inertial loads generated by the oscillatory motion of the model. Thus, to obtain the aerodynamic loads, they have to be separated from the inertial loads. In the present tests the intertial loads were calculated from the displacements measured with the accelerometers in the launcher and the known physical quantities (mass, moment of inertia and c.g. location) of the store configuration under consideration.

In the case of a harmonically pitching motion, the following formulas apply for the inertial force (K^*) and moment (M^*) acting at the centre of the balance (see also Fig. 12):

$$K^* = m\,(\ddot{z} + \ddot{\Theta}\sigma\ell) \tag{1}$$

and

$$M^* = -I\ddot{\Theta} - m\,(\ddot{z} + \ddot{\Theta}\sigma\ell)\sigma\ell \quad . \tag{2}$$

In (1) and (2) $\ddot{z}$ and $\ddot{\Theta}$ denote the accelerations of and around the centre of the balance. The quantities m, $\sigma\ell$ and I denote the mass, centre of gravity location and moment of inertia of the store, respectively. It should be noted that the inertial quantities include that part of the balance which oscillates with the store.

Once the accelerations and inertial data are known, the aerodynamic contribution follows from:

$$K_{aero} = K_{total} - m(\ddot{z} + \ddot{\Theta}\sigma\ell) \tag{3}$$

and

$$M_{aero} = M_{total} + I\ddot{\Theta} + m(\ddot{z} + \ddot{\Theta}\sigma\ell)\sigma\ell \quad . \tag{4}$$

Similar formulas are applicable to the measurements of the aerodynamic side force and yawing moment (see also Fig. 12).

The physical quantities of the store in its various stages of completeness were determined in separate oscillation tests, the results of which were checked against calculations. Table 2 summarizes the values used in the data reduction procedure. It should be noted that for the underwing store this table does not differentiate between in plane and out of plane measurements. The reason is that the out of plane displacements were so small that the small differences in physical properties did not influence the final results for the aerodynamic loads.

It was found that the above procedure works very satisfactory for frequencies up to 30 Hz. At lower frequencies the aerodynamic loads appear to be of the same order as the inertial loads. However, at the higher frequencies the inertial loads increase considerably and dominate the aerodynamic loads to a large extent, with that reducing the accuracy of the measurements. Moreover, above 30 Hz the store no longer could be considered as a rigid body.

4 MEASURING EQUIPMENT AND DATA REDUCTION

The wind-tunnel tests were performed with the help of a processor ("PHAROS") designed for unsteady measurements (Ref. 8). This computer controlled device, performes a series of tasks. It controls the model excitation through a two phase oscillator with variable frequency. It accepts simultaneously some 50 measuring signals, which then are fed through conditioners and transfer function analyzers to obtain the steady component and the real and imaginary part of the harmonic components. Next it stores these data and performs a quick-look analysis on a selected set of these data. A block diagram of the apparatus is presented in figure 13.

The final data reduction took place on a larger computer. Following the procedure described in section 3.1, the transfer functions were determined and the measured unsteady pressures were transformed into quantities pertaining to the model surface. As far as the load measurements are concerned, first the readings of the various components of the balance were reduced to the actual forces and moments.

Next the unsteady aerodynamic loads were extracted following the method given in section 3.2. Finally, the displacements measured by the accelerometers in the wing were reduced to local amplitudes and normalized with respect to the displacement of accelerometer 2 (see Fig. 4).

As a result, the following quantities were obtained (for definitions, see appendix I.A):

- the chordwise distribution of the (mean) steady pressure coefficient C_p;
- the chordwise distribution of the unsteady pressure coefficient C_{p_i}, normalized with respect to the angular displacement of the wing in the section of accelerometer 1 and 2;
- sectional steady and unsteady lift and moment coefficients obtained by integration of the pressure distributions;
- overall steady force and moment coefficients on the store;
- overall unsteady force and moment coefficients on the store normalized with respect to the same angular displacement.
- vibration modes of wing and store.

5 THE TESTPROGRAM

5.1 The clean wing

The tests on the clean wing covered the Mach number range between Ma = .6 and Ma = 1.35; the frequencies of oscillation were 10, 20, 30 and 40 Hz. The maximum values of the reduced frequency achieved during the tests varied from K = .4 at Ma = .6 to K = .2 at Ma = 1.35. The tests were performed at a mean steady incidence of nearly zero degrees and with amplitudes of oscillation between .1 and .5 degrees.

To determine the unsteady airloads for zero frequency ("quasi-steady" results), a series of steady measurements was carried out at incidences of $\alpha = -.5^{\circ}$, 0° and $+.5^{\circ}$, respectively.
A survey of the testprogram for the clean wing is shown in table 3.

5.2 The wing equipped with store

The tests on the wing with store configurations were performed also for a Mach number range between Ma = 0.6 and Ma = 1.35, except in the case of configurations with the underwing missile in-

stalled (configurations 301 and 31). For the latter configurations the Ma-range was limited to $0.9 \leq Ma \leq 1.35$ and $0.6 \leq Ma \leq 0.9$ respectively. The reason for this is, that during the test with configuration 301, a fatigue failure did make the canard fins disappear from the model.
The frequency of oscillation applied was 20 and 40 Hz. For configurations 4 and 20 (see table 1) some additional experiments were performed at 10 Hz and 30 Hz. During the steady measurements again the following incidences were taken: $\alpha = -.5^o$, 0^o and $+.5^o$.

The detailed testprogram (steady and unsteady) of the tip-mounted store configurations is given in table 4, while table 5 contains the testprogram for the underwing-store configuration.

6 FINAL REMARK

In this report a survey is given of the general test set-up and test procedures of the wind-tunnel tests on an oscillating wing equipped with external store.

As already mentioned in section 1, the results and a discussion hereabout are presented in subsequent parts of this report: Part II containing the results of the clean wing and parts III and IV giving similar data for the tip-store and the underwing-store configurations. Moreover the test data are gathered in tabulated form (Ref. 3).

7 ACKNOWLEDGEMENT

The National Aerospace Laboratory expresses its gratitude to the Royal Netherlands Air Force (RNLAF) for their permission to use the F-5 wing model for the present investigation.

The development of the strain gage balances and the associated reduction procedure to obtain the aerodynamic loads was sponsored by the RNLAF as well.

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APPENDIX I.A

Definitions of steady and unsteady aerodynamic quantities *)

Definitions of pressure, force and moment coefficients for the wing

Steady

Pressure coefficient C_p :

$$C_p = (P_{loc} - P)/Q \quad .$$

Sectional normal force :

$$Z = C_z QC \ , \ C_z = - \int_0^1 (C_{p+} - C_{p-}) \, d(x/C) \quad .$$

Sectional pitching moment about quarter chord point (positive nose down) :

$$M = C_m QC^2 \ , \ C_m = - \int_0^1 (C_{p+} - C_{p-}) \, (x/C - 0.25) \, d(x/C) \quad .$$

Unsteady

Pressure coefficient C_{pi} :

$$C_{pi} = \mathrm{Re}C_{pi} + i\,\mathrm{Im}C_{pi} = P_i/Q\Theta \quad .$$

Sectional normal force :

$$Z_i = \pi QCC_{zi}\Theta e^{i\omega t} \ , \ C_{zi} = \mathrm{Re}C_{zi} + i\,\mathrm{Im}C_{zi} = - \frac{1}{\pi} \int_0^1 (C_{pi+} - C_{pi-}) \, d(x/C) \quad .$$

Sectional pitching moment about quarter chord point (positive nose down) :

$$M_i = \frac{\pi}{2} QC^2 \, C_{mi} \Theta e^{i\omega t} \ ,$$

$$C_{mi} = \mathrm{Re}C_{mi} + i\,\mathrm{Im}C_{mi} = - \frac{2}{\pi} \int_0^1 (C_{pi+} - C_{pi-}) \, (x/C - 0.25) \, d(x/C) \quad .$$

---

*) The definitions for the unsteady aerodynamic quantities are according to the AGARD manual on Aeroelasticitiy vol. VI (Ref. 9).

Quasi-steady at zero incidence ($\omega = 0;\ \alpha_o = 0$)

Pressure coefficient C_{pq} :

$$C_{pq} = \Delta C_p/\Delta\alpha = \frac{C_p(\alpha_o + \Delta\alpha_1) - C_p(\alpha_o - \Delta\alpha_2)}{\Delta\alpha_1 + \Delta\alpha_2} .$$

Sectional normal force :

$$Z_q = \pi Q C C_{zq} \Theta e^{i\omega t} , \quad C_{zq} = \frac{1}{\pi} \Delta C_z/\Delta\alpha = \frac{1}{\pi} \frac{C_z(\alpha_o + \Delta\alpha_1) - C_z(\alpha_o - \Delta\alpha_2)}{\Delta\alpha_1 + \Delta\alpha_2} .$$

Sectional pitching moment (positive nose down):

$$M_q = \frac{\pi}{2} Q C C_{mq} \Theta e^{i\omega t} , \quad C_{mq} = \frac{2}{\pi} \Delta C_m/\Delta\alpha = \frac{2}{\pi} \frac{C_m(\alpha_o + \Delta\alpha_1) - C_m(\alpha_o - \Delta\alpha_2)}{\Delta\alpha_1 + \Delta\alpha_2} .$$

Definitions of force and moment coefficients of pylon and store

Steady

Normal force :

$$Z = C_z Q \bar{C} S .$$

Side force :

$$Y = C_y Q \bar{C} S .$$

Pitching moment about balance centre (positive nose up) :

$$M = C_m Q \bar{C}^2 S .$$

Yawing moment about balance centre (positive nose inward) :

$$N = C_n Q \bar{C}^2 S .$$

Unsteady

Normal force :

$$Z_i = \pi Q \bar{C} S C_{zi} \Theta e^{i\omega t} , \quad C_{zi} = \mathrm{Re}C_{zi} + i\,\mathrm{Im}C_{zi} .$$

Side force :

$$Y_i = \pi Q\bar{C}SC_{yi}\Theta e^{i\omega t}, \; C_{yi} = ReC_{yi} + i\,ImC_{yi} \; .$$

Pitching moment about balance centre (positive nose up) :

$$M_i = \frac{\pi}{2} Q\bar{C}^2SC_{mi}\Theta e^{i\omega t}, \; C_{mi} = ReC_{mi} + i\,ImC_{mi} \; .$$

Yawing moment about balance centre (positive nose inward) :

$$N_i = \frac{\pi}{2} Q\bar{C}^2SC_{ni}\Theta e^{i\omega t}, \; C_{ni} = ReC_{ni} + i\,ImC_{ni} \; .$$

<u>Quasi-steady at zero incidence</u> ($\omega = 0;\ \alpha_o = 0$)

Normal force :

$$Z_i = \pi Q\bar{C}SC_{zq}\Theta e^{i\omega t} \; ,$$

$$C_{zq} = \frac{1}{\pi} \Delta C_z/\Delta\alpha = \frac{1}{\pi} \frac{C_z(\alpha_o + \Delta\alpha_1) - C_z(\alpha_o - \Delta\alpha_2)}{\Delta\alpha_1 + \Delta\alpha_2} \; .$$

Side force :

$$Y_i = \pi Q\bar{C}SC_{yq}\Theta e^{i\omega t}$$

$$C_{yq} = \frac{1}{\pi} \Delta C_y/\Delta\alpha = \frac{1}{\pi} \frac{C_y(\alpha_o + \Delta\alpha_1) - C_y(\alpha_o - \Delta\alpha_2)}{\Delta\alpha_1 + \Delta\alpha_2} \; .$$

Pitching moment about balance centre (positive nose up):

$$M_i = \frac{\pi}{2} Q\bar{C}^2SC_{mq}\Theta e^{i\omega t}$$

$$C_{mq} = \frac{2}{\pi} \Delta C_m/\Delta\alpha = \frac{2}{\pi} \frac{C_m(\alpha_o + \Delta\alpha_1) - C_m(\alpha_o - \Delta\alpha_2)}{\Delta\alpha_1 + \Delta\alpha_2} \; .$$

Yawing moment about balance centre (positive nose inward):

$$N_i = \frac{\pi}{2} Q\bar{C}^2SC_{nq}\Theta e^{i\omega t}$$

$$C_{nq} = \frac{2}{\pi} \Delta C_n/\Delta\alpha = \frac{2}{\pi} \frac{C_n(\alpha_o + \Delta\alpha_1) - C_n(\alpha_o - \Delta\alpha_2)}{\Delta\alpha_1 + \Delta\alpha_2} \; .$$

TABLE 1

Survey of model configurations

CONF.	DESCRIPTION
0	WING
1	WING AND TIPLAUNCHER
2	WING, TIPLAUNCHER AND MISSILE BODY
3	WING, TIPLAUNCHER AND MISSILE BODY WITH AFT WINGS
4	WING, TIPLAUNCHER AND COMPLETE MISSILE
10	WING AND PYLON
20	WING, PYLON AND LAUNCHER
31	WING, PYLON, LAUNCHER AND MISSILE BODY WITH AFT WINGS
301	WING, PYLON, LAUNCHER AND COMPLETE MISSILE

TABLE 2

Survey of physical quantities used to determine the inertial loads

CONF.	DESCRIPTION	m (kg)	$\sigma\ell$ (m)	I (kgm^2)
1	TIP LAUNCHER (TL)	.535	-.0337	.0081
2	TL + MISSILE BODY (MB)	.664	-.0592	.0146
3	TL, MB + AFT WINGS	.720	-.0417	.0167
4	TL + MISSILE (COMPLETE)	.770	-.065	.0217
20	PYLON LAUNCHER (PL)	.490	-.0375	.0085
31	PL + MB + AFT WINGS	.680	-.0475	.0178
301	PL + MISSILE (COMPLETE)	.690	-.0525	.0183

TABLE 3

Test program

CONF. 0 (CLEAN WING)

STEADY TESTS	RUN	Ma	Alpha (°)	$P_o \times 10^{-5}$ (Pa)
	136	.6	- .5	1.0
	137	.6	0	
	138	.6	+ .5	
	145	.8	- .5	
	146	.8	0	
	147	.8	+ .5	
	150	.9	- .5	
	151	.9	0	
	152	.9	+ .5	
	157	.95	- .5	
	158	.95	0	
	159	.95	+ .5	
	162	1.05	- .5	
	163	1.05	0	
	164	1.05	+ .5	
	167	1.10	- .5	
	168	1.10	0	
	169	1.10	+ .5	1.0
	184	1.20	- .5	.7
	185	1.20	0	
	186	1.20	+ .5	
	189	1.35	- .5	
	190	1.35	0	
	191	1.35	+ .5	.7

TABLE 3

Test program

(Cont'd)

CONF. 0 (CLEAN WING)

UNSTEADY TESTS	RUN	Ma	FREQUENCY (Hz)	RED.FREQ.	THETA (^{o})	$P_o \times 10^{-5}$ (pa)
	380	.6	10	.100	.108	1.0
	382	.6	20	.199	.106	
	381	.6	30	.299	.11	
	383	.6	40	.399	.115	
	367	.8	20	.153	.108	
	368	.8	40	.307	.113	
	378	.9	10	.068	.108	
	369	.9	20	.137	.109	
	379	.9	30	.206	.108	
	370	.9	40	.275	.111	
	160	.95	20	.132	.523	
	161	.95	40	.264	.222	
	375	1.00	20	.125	.107	
	376	1.00	40	.250	.112	
	165	1.05	20	.122	.522	
	166	1.05	40	.243	.219	
	373	1.10	10	.058	.113	
	172	1.10	20	.116	.267	
	374	1.10	30	.173	.110	
	372	1.10	40	.231	.112	1.0
	187	1.20	20	.109	.524	.7
	188	1.20	40	.218	.222	
	192	1.35	20	.100	.523	
	193	1.35	40	.198	.222	.7

TABLE 4
Test program

CONF. 1 (WING + TIPLAUNCHER)

STEADY TESTS

RUN	Ma	ALPHA (°)	$P_o \times 10^{-5}$ (Pa)
197	.6	- .5	1.0
198	.6	0	
199	.6	+ .5	
206	.9	- .5	
208	.9	0	
209	.9	+ .5	
212	1.10	- .5	
213	1.10	0	
214	1.10	+ .5	1.0
223	1.10	- .5	.7
224	1.10	0	
225	1.10	+ .5	
217	1.35	- .5	
218	1.35	0	
220	1.35	+ .5	.7

UNSTEADY TESTS

RUN	Ma	FREQUENCY (Hz)	RED.FREQ.	THETA (°)	$P_o \times 10^{-5}$ (Pa)
202	.6	20	.202	.111	1.0
204	.6	40	.402	.114	
210	.9	20	.138	.530	
211	.9	40	.276	.224	
215	1.10	20	.116	.531	
216	1.10	40	.232	.226	1.0
226	1.10	20	.117	.526	.7
227	1.10	40	.234	.117	
221	1.35	20	.100	.529	
222	1.35	40	.200	.115	.7

TABLE 4
Test program
(Cont'd)

CONF. 2 (WING + TIPLAUNCHER + MISSILE BODY)

STEADY TESTS	RUN	Ma	ALPHA (°)	$P_o \times 10^{-5}$ (Pa)
	255	.6	- .5	1.0
	256	.6	0	
	257	.6	+ .5	
	249	.9	- .5	
	251	.9	0	
	252	.9	+ .5	
	244	1.10	- .5	
	245	1.10	0	
	246	1.10	+ .5	1.0
	233	1.35	- .5	.7
	234	1.35	0	.7
	235	1.35	+ .5	.7

UNSTEADY TESTS	RUN	Ma	FREQUENCY (Hz)	RED.FREQ.	THETA (°)	$P_o \times 10^{-5}$ (Pa)
	258	.6	20	.201	.524	1.0
	259	.6	40	.402	.221	
	253	.9	20	.138	.532	
	254	.9	40	.276	.223	
	247	1.10	20	.116	.530	
	248	1.10	40	.232	.230	1.0
	242	1.10	20	.116	.525	.7
	243	1.10	40	.232	.223	
	236	1.35	20	.100	.532	
	237	1.35	40	.199	.111	.7

TABLE 4
Test program
(Cont'd)

CONF. 3 (WING + TIPLAUNCHER + MISSILE BODY + AFT WINGS)

STEADY TESTS	RUN	Ma	ALPHA (^{o})	$P_o \times 10^{-5}$ (Pa)
	285	.6	- .5	1.0
	286	.6	0	
	287	.6	+ .5	
	280	.9	- .5	
	281	.9	0	
	282	.9	+ .5	
	274	1.10	- .5	
	275	1.10	0	
	276	1.10	+ .5	1.0
	269	1.10	- .5	.7
	270	1.10	0	
	271	1.10	+ .5	
	264	1.35	- .5	
	265	1.35	0	
	266	1.35	+ .5	.7

UNSTEADY TESTS	RUN	Ma	FREQUENCY (Hz)	RED.FREQ.	THETA (^{o})	$P_o \times 10^{-5}$ (Pa)
	288	.6	20	.201	.525	1.0
	289	.6	40	.401	.220	
	283	.9	20	.139	.534	
	284	.9	40	.279	.222	
	277	1.10	20	.116	.522	
	278	1.10	40	.232	.226	1.0
	272	1.10	20	.117	.524	.7
	273	1.10	40	.234	.113	
	267	1.35	20	.100	.527	
	268	1.35	40	.200	.220	.7

TABLE 4

Test program
(Cont'd)

CONF. 4 (WING + TIPLAUNCHER + MISSILE BODY + AFT WINGS + CANARD FINS)

STEADY TESTS

RUN	Ma	ALPHA (^{o})	$P_o \times 10^{-5}$ (Pa)
340	.6	- .5	1.0
341	.6	0	
342	.6	+ .5	
333	.7	- .5	
334	.7	0	
335	.7	+ .5	
326	.8	- .5	
327	.8	0	
328	.8	+ .5	
319	.9	- .5	
320	.9	0	
321	.9	+ .5	
312	1.10	- .5	
313	1.10	0	
314	1.10	+ .5	1.0
303	1.10	- .5	.7
306	1.10	0	
307	1.10	+ .5	
295	1.35	- .5	
297	1.35	0	
298	1.35	+ .5	.7

TABLE 4

Test program
(Cont'd)

CONF. 4 (WING + TIPLAUNCHER + MISSILE BODY + AFT WINGS + CANARD FINS)

UNSTEADY TESTS	RUN	Ma	FREQUENCY (Hz)	RED.FREQ.	THETA ($^{\circ}$)	$P_o \times 10^{-5}$ (Pa)
	351	.6	10	.100	.109	1.0
	350	.6	20	.200	.114	
	344	.6	20	.200	.527	
	349	.6	30	.300	.109	
	348	.6	40	.401	.111	
	336	.7	10	.086	.535	
	337	.7	20	.173	.528	
	338	.7	30	.260	.375	
	339	.7	40	.346	.225	
	357	.8	10	.076	.110	
	358	.8	20	.153	.108	
	359	.8	30	.229	.110	
	360	.8	40	.305	.115	
	352	.9	10	.069	.115	
	353	.9	20	.138	.110	
	354	.9	30	.207	.110	
	355	.9	40	.275	.117	
	315	1.10	10	.058	.547	
	316	1.10	20	.116	.527	
	317	1.10	30	.174	.376	
	318	1.10	40	.231	.228	1.0
	308	1.10	10	.058	.536	.7
	309	1.10	20	.117	.519	
	310	1.10	30	.175	.375	
	311	1.10	40	.234	.224	
	299	1.35	10	.051	.532	
	300	1.35	20	.101	.526	
	301	1.35	30	.149	.374	
	302	1.35	40	.199	.221	.7

TABLE 5
Test program

CONF. 10 (WING + PYLON)

STEADY TESTS	RUN	Ma	ALPHA (^{o})	$P_o \times 10^{-5}$ (Pa)
	125	.6	- .5	1.0
	126	.6	0	
	127	.6	+ .5	
	120	.9	- .5	
	121	.9	0	
	122	.9	+ .5	
	116	1.1	- .5	
	117	1.1	0	
	118	1.1	+ .5	1.0
	106	1.1	- .5	.7
	107	1.1	0	
	108	1.1	+ .5	
	101	1.35	- .5	
	102	1.35	0	.7

UNSTEADY TESTS	RUN	Ma	FREQUENCY (Hz)	RED.FREQ.	THETA (^{o})	$P_o \times 10^{-5}$ (Pa)
	128	.6	20	.199	.526	1.0
	129	.6	40	.399	.223	
	123	.9	20	.137	.529	
	124	.9	40	.273	.221	
	114	1.1	20	.115	.532	
	115	1.1	40	.231	.220	1.0
	109	1.1	20	.117	.524	.7
	110	1.1	40	.233	.223	
	104	1.35	20	.099	.528	
	105	1.35	40	.199	.223	.7

TABLE 5
Test program
(Cont'd)

CONF. 20 (WING + PYLON + LAUNCHER)

STEADY TESTS	RUN	Ma	ALPHA (^{o})	$P_o \times 10^{-5}$ (Pa)
	54	.6	- .5	.7
	55	.6	0	
	56	.6	+ .5	
	61	.9	- .5	
	62	.9	0	
	63	.9	+ .5	
	68	1.1	- .5	
	69	1.1	0	
	70	1.1	+ .5	
	75	1.35	- .5	
	76	1.35	0	
	77	1.35	+ .5	.7

UNSTEADY TESTS	RUN	Ma	FREQUENCY (Hz)	RED.FREQ.	THETA (^{o})	$P_o \times 10^{-5}$ (Pa)
	57	.6	10	.101	.523	.7
	58	.6	20	.201	.518	
	59	.6	30	.303	.370	
	60	.6	40	.403	.229	
	64	.9	10	.070	.533	
	65	.9	20	.140	.519	
	66	.9	30	.210	.375	
	67	.9	40	.279	.226	
	71	1.1	10	.059	.534	
	72	1.1	20	.118	.526	
	73	1.1	30	.176	.371	
	74	1.1	40	.234	.223	
	78	1.35	10	.050	.529	
	79	1.35	20	.099	.524	
	80	1.35	30	.149	.372	
	81	1.35	40	.199	.228	.7

TABLE 5

Test program
(Cont'd)

CONF. 301 (WING + PYLON + LAUNCHER + MISSILE WITHOUT CANARD FINS)

STEADY TESTS	RUN	Ma	ALPHA (^{o})	$P_o \times 10^{-5}$ (Pa)
	89	1.1	- .5	.7
	90	1.1	0	
	91	1.1	+ .5	
	94	1.35	- .5	
	95	1.35	0	
	96	1.35	+ .5	.7

UNSTEADY TESTS	RUN	Ma	FREQUENCY (Hz)	RED.FREQ.	THETA (^{o})	$P_o \times 10^{-5}$ (Pa)
	88	.9	20	.141	.521	1.0
	87	.9	40	.281	.226	1.0
	92	1.1	20	.118	.521	.7
	93	1.1	40	.235	.222	
	97	1.35	20	.099	.522	
	98	1.35	40	.199	.223	.7

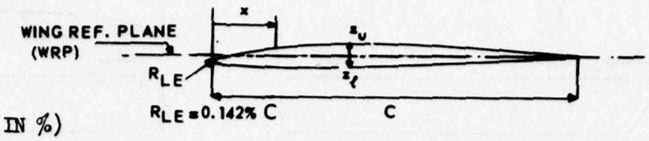
TABLE 5

Test program
(Cont'd)

CONF. 31 (WING + PYLON + LAUNCHER + COMPLETE MISSILE)

STEADY TESTS	RUN	Ma	ALPHA (^{o})	$P_o \times 10^{-5}$ (Pa)
	40	.6	- .5	1.0
	41	.6	0	
	42	.6	+ .5	
	45	.9	- .5	
	46	.9	0	
	47	.9	+ .5	1.0

UNSTEADY TESTS	RUN	Ma	FREQUENCY (Hz)	RED.FREQ.	THETA (^{o})	$P_o \times 10^{-5}$ (Pa)
	43	.6	20	.201	.527	1.0
	44	.6	40	.400	.230	
	48	.9	20	.138	.524	
	49	.9	40	.276	.225	1.0



AEROFOIL CO-ORDINATES (IN %)

x/C	z_u/C	z_ℓ/C
0	-1.03300	-1.03300
0.1	-0.85917	-1.19123
0.2	-0.78409	-1.25078
0.3	-0.72529	-1.29413
0.4	-0.67494	-1.32912
0.5	-0.62999	-1.35879
0.6	-0.58889	-1.38470
0.7	-0.55074	-1.40774
0.8	-0.51489	-1.42855
0.9	-0.48095	-1.44754
1.0	-0.44861	-1.46502
1.25	-0.37338	-1.50342
1.50	-0.30440	-1.53608
1.75	-0.24019	-1.56446
2.00	-0.17980	-1.58950
2.25	-0.12256	-1.61188
2.50	-0.06801	-1.63204
3.00	0.03448	-1.66716
4.00	0.21918	-1.72259
5.00	0.38403	-1.76521
6.00	0.53408	-1.79977
7.00	0.67239	-1.82904
8.00	0.80092	-1.85474
9.00	0.92107	-1.87801
10	1.03386	-1.89966
11	1.14006	-1.92024
12	1.24024	-1.94013
13	1.33490	-1.95962

x/C	z_u/C	z_ℓ/C
14	1.42438	-1.97891
15	1.50900	-1.99811
16	1.58897	-2.01730
17	1.66449	-2.03650
18	1.73574	-2.05568
19	1.80284	-2.07488
20	1.86588	-2.09407
21	1.92499	-2.11326
22	1.98022	-2.13245
23	2.03164	-2.15164
24	2.07933	-2.17083
25	2.12334	-2.19002
26	2.16373	-2.20921
27	2.20056	-2.22840
28	2.23391	-2.24760
29	2.26384	-2.26679
30	2.29043	-2.28598
31	2.31376	-2.30509
32	2.33396	-2.32367
33	2.35113	-2.34117
34	2.36540	-2.35704
35	2.37693	-2.37079
36	2.38588	-2.38202
37	2.39243	-2.39049
38	2.39681	-2.39614
39	2.39924	-2.39915
40	2.40000	-2.40000

x/C	$z_u/C (= z_\ell/C)$
41	2.39930
42	2.39720
43	2.39372
44	2.38885
45	2.38260
46	2.37496
47	2.36597
48	2.35560
49	2.34387
50	2.33078
51	2.31633
52	2.30054
53	2.28341
54	2.26493
55	2.24512
56	2.22398
57	2.20152
58	2.17774
59	2.15263
60	2.12622
61	2.09850
62	2.06948
63	2.03916
64	2.00755
65	1.97465
66	1.94047
67	1.90501
68	1.86814
69	1.82961
70	1.78920

x/C	$z_u/C (= z_\ell/C)$
71	1.74675
72	1.70213
73	1.65530
74	1.60623
75	1.55497
76	1.50162
77	1.44631
78	1.38924
79	1.33066
80	1.27087
81	1.21023
82	1.14913
83	1.08798
84	1.02680
85	0.96563
86	0.90445
87	0.84328
88	0.78210
89	0.72093
90	0.65975
91	0.59858
92	0.53740
93	0.47623
94	0.41505
95	0.35388
96	0.29270
97	0.23153
98	0.17035
99	0.10918
100	0.04800

Co-ordinates of the aerofoil of the wing

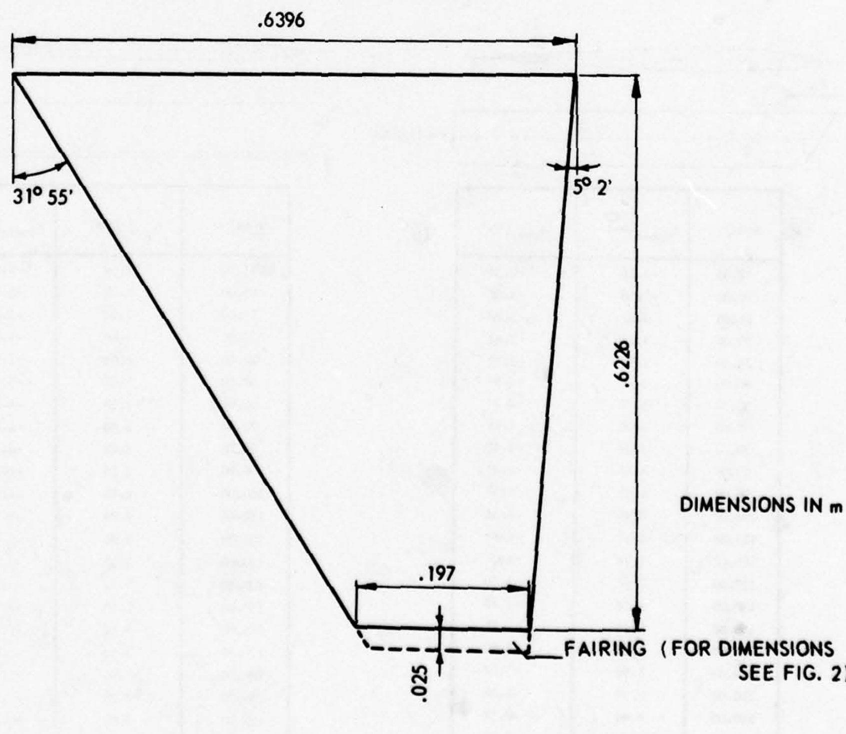
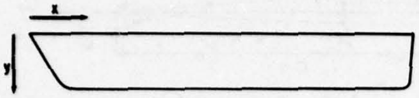
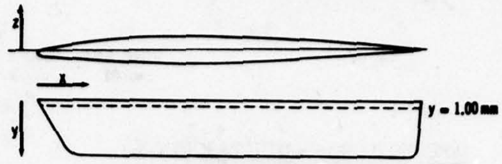


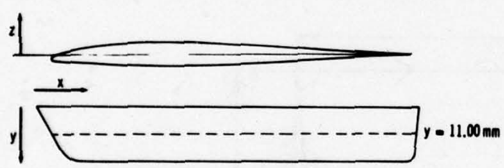
Fig. 1 Dimensions of the wing



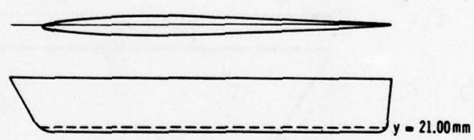
x(mm)	y(mm)
0.46	1.00
3.56	6.00
6.66	11.00
9.80	16.00
14.58	21.00
16.00	22.00
17.78	23.00
20.24	24.00
30.00	24.98
100.00	25.00
160.00	25.02
170.00	24.90
180.00	24.38
190.00	23.54
192.00	23.08
194.00	21.52
196.10	1.00



x(mm)	z_{upper} (mm)	z_{lower}(mm)
1.00	-1.58	-2.68
5.00	-0.38	-3.18
10.00	0.56	-3.38
20.00	1.94	-3.68
30.00	2.86	-3.90
40.00	3.56	-4.12
50.00	4.06	-4.32
60.00	4.38	-4.48
70.00	4.56	-4.60
80.00	4.62	-4.64
90.00	4.56	-4.64
100.00	4.46	-4.54
110.00	4.28	-4.36
120.00	4.00	-4.10
130.00	3.70	-3.76
140.00	3.30	-3.32
150.00	2.80	-2.80
160.00	2.24	-2.26
170.00	1.64	-1.68
180.00	1.02	-1.12
190.00	0.40	-0.54
195.00	0.13	-0.19



x(mm)	z_{upper}(mm)	z_{lower}(mm)
7.00	-1.66	-2.58
10.00	-0.58	-3.06
15.00	0.42	-3.28
20.00	1.18	-3.44
25.00	1.80	-3.70
40.00	3.12	-3.90
50.00	3.70	-4.10
60.00	4.08	-4.28
70.00	4.34	-4.40
80.00	4.44	-4.48
90.00	4.43	-4.52
100.00	4.34	-4.44
110.00	4.18	-4.28
120.00	3.94	-4.02
130.00	3.62	-3.70
140.00	3.24	-3.28
150.00	2.76	-2.76
160.00	2.18	-2.20
170.00	1.59	-1.64
180.00	0.98	-1.08
190.00	0.40	-0.52
195.00	0.04	-0.22



x(mm)	z_{upper}(mm)	z_{lower}(mm)
15.00	-1.54	-2.66
20.00	0.20	-3.20
25.00	1.02	-3.38
30.00	1.66	-3.50
40.00	2.64	-3.72
50.00	3.32	-3.92
60.00	3.78	-4.08
70.00	4.08	-4.22
80.00	4.24	-4.30
90.00	4.26	-4.36
100.00	4.18	-4.32
110.00	4.04	-4.18
120.00	3.80	-3.96
130.00	3.52	-3.66
140.00	3.14	-3.26
150.00	2.68	-2.74
160.00	2.12	-2.18
170.00	1.52	-1.60
180.00	0.90	-1.03
190.00	0.28	-0.46
194.00	0.00	-0.22

Fig. 2 Co-ordinates tip fairing

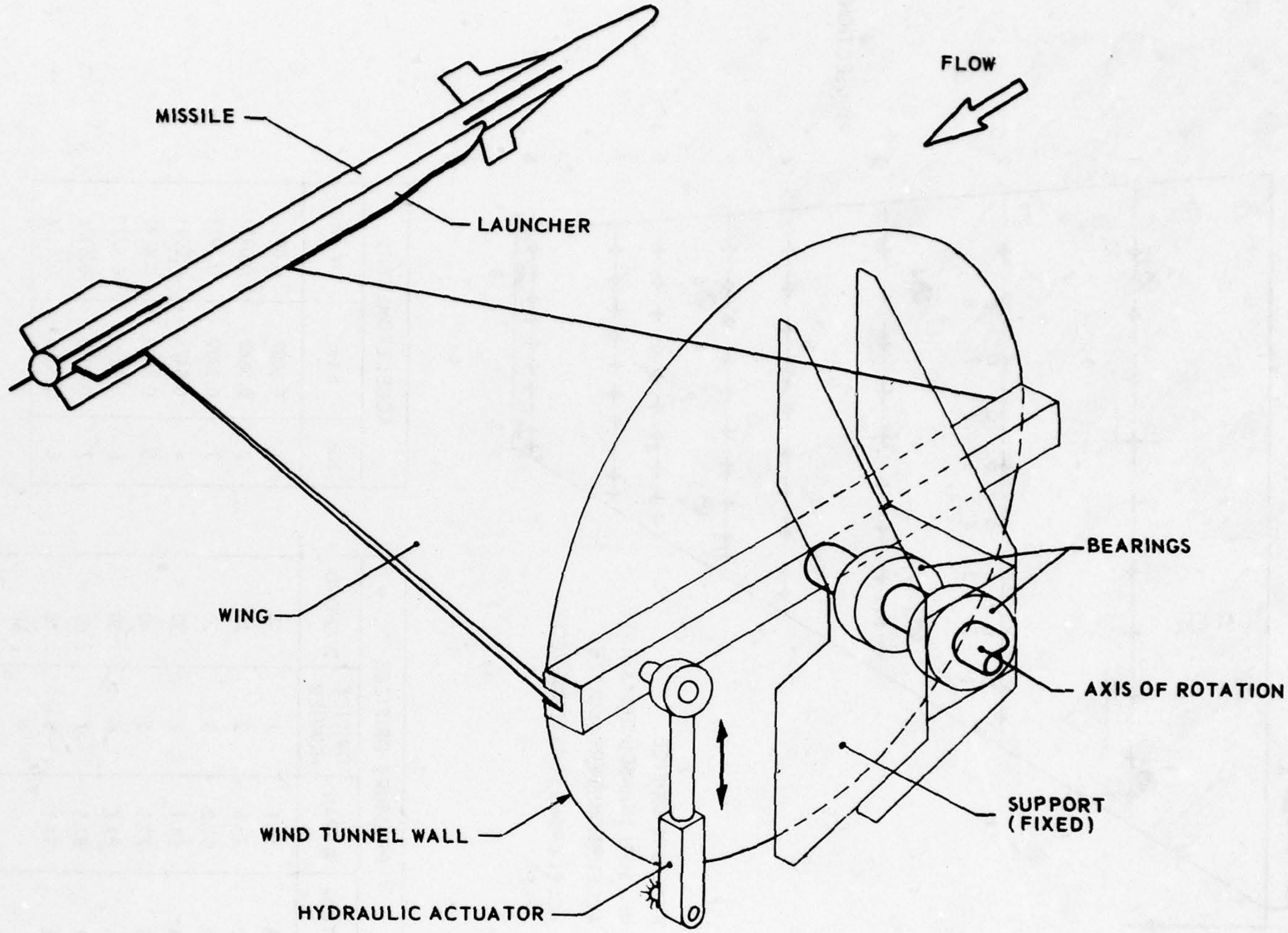
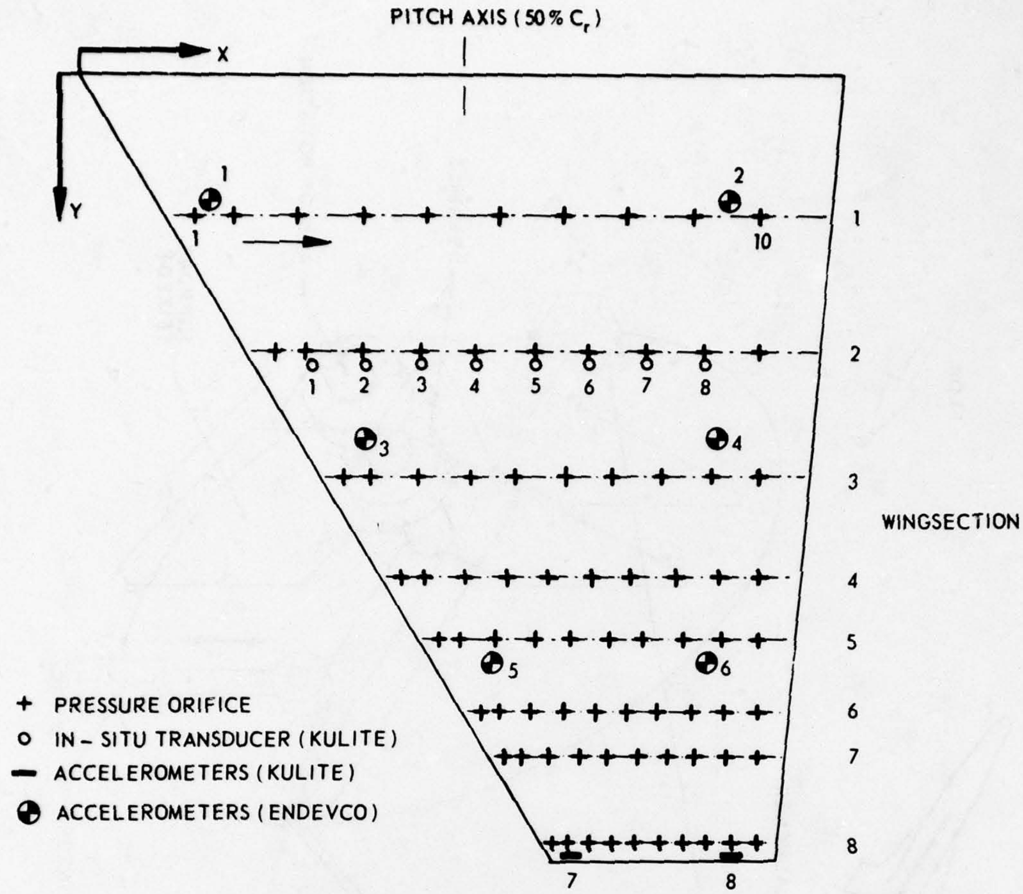


Fig. 3 Schematic view of the test set up



PRESSURE ORIFICES			
SECTION	% SPAN	ORIFICE NUMBER	% CHORD
1	18.1	1	3
2	35.5	2	10
3	51.2	3	20
4	64.1	4	30
5	72.1	5	40
6	81.7	6	50
7	87.5	7	60
8	97.7	8	70
		9	80
		10	90

ACCELEROMETERS		
NR	X (m)	Y (m)
1	0.1087	0.0957
2	0.5648	0.0977
3	0.2309	0.2971
4	0.5475	0.2991
5	0.3422	0.4772
6	0.5270	0.4772
7	0.4070	0.6176
8	0.5390	0.6176

Fig. 4 Location of pressure orifices and transducers

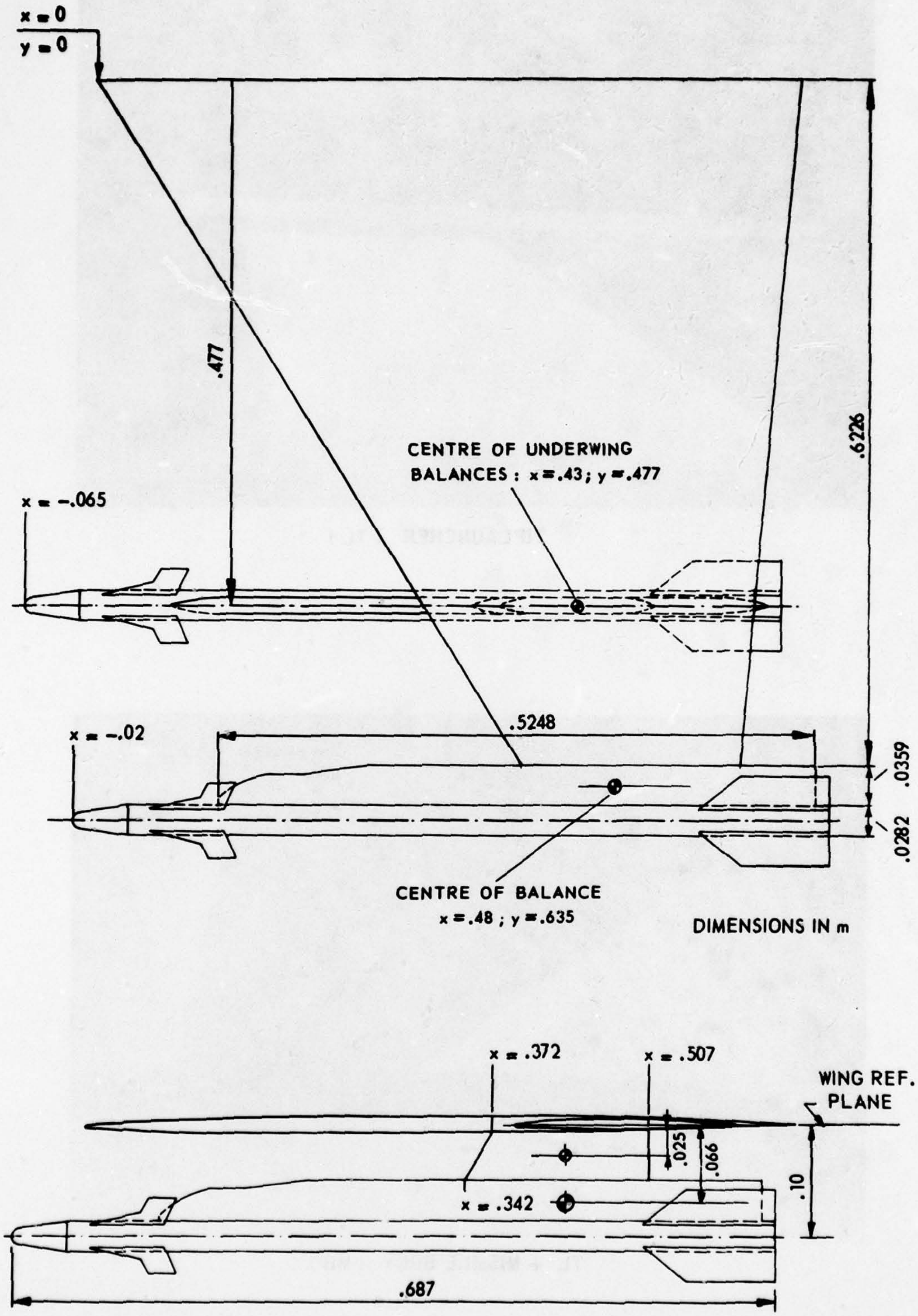
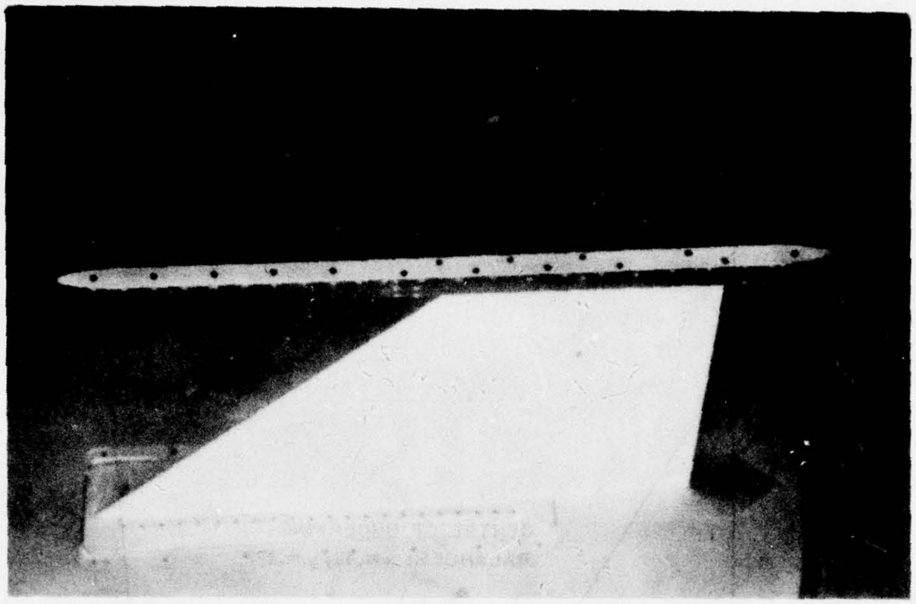
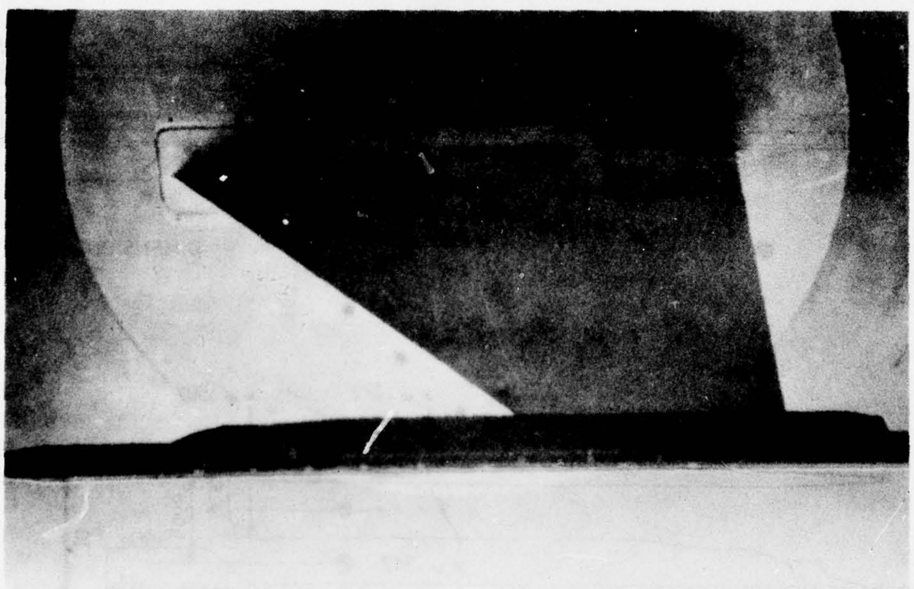


Fig. 5 Position of the store and strain gage balances

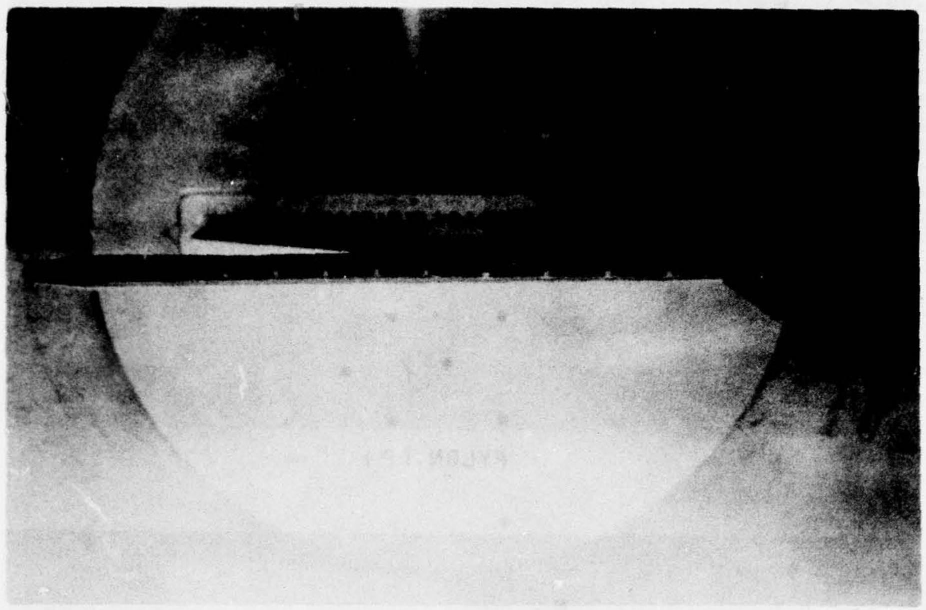


TIPLAUNCHER (TL)

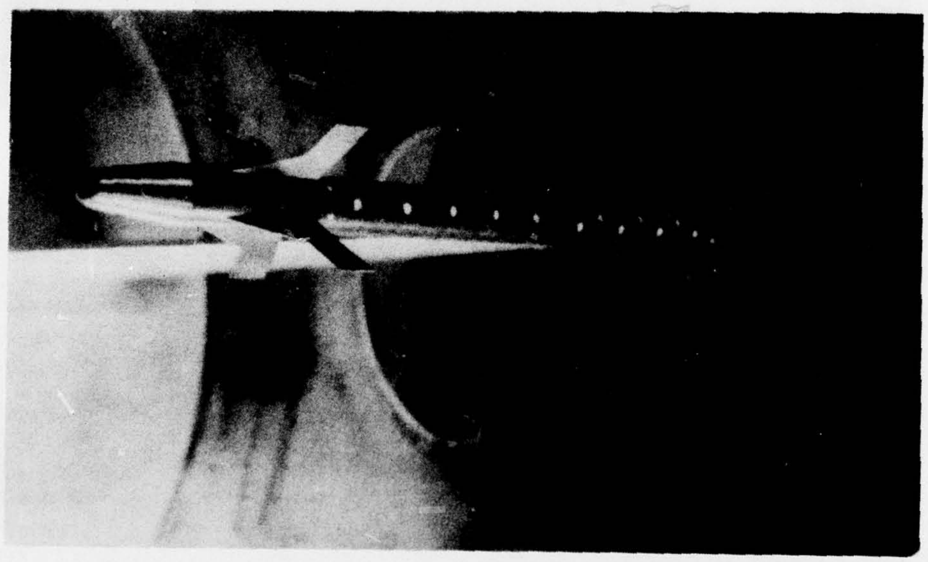


TL + MISSILE BODY (MB)

Fig. 6a Photographs of various tip store configurations

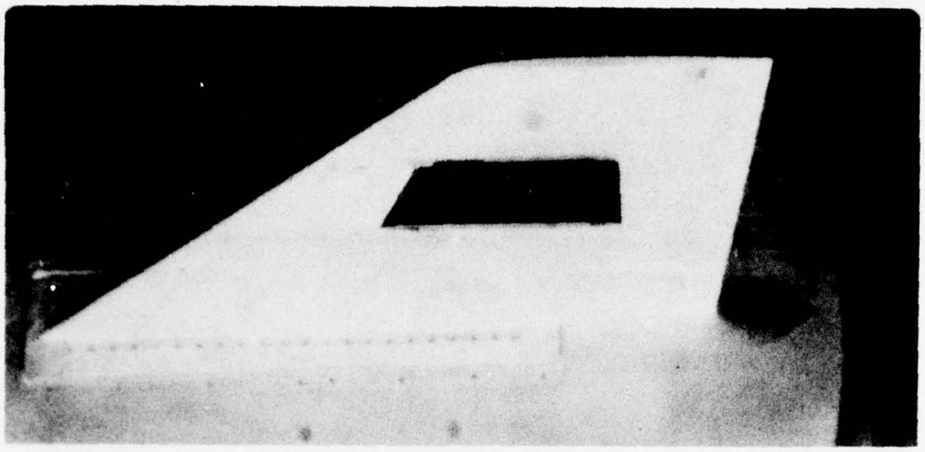


TL + MB + AFT WINGS (AW)

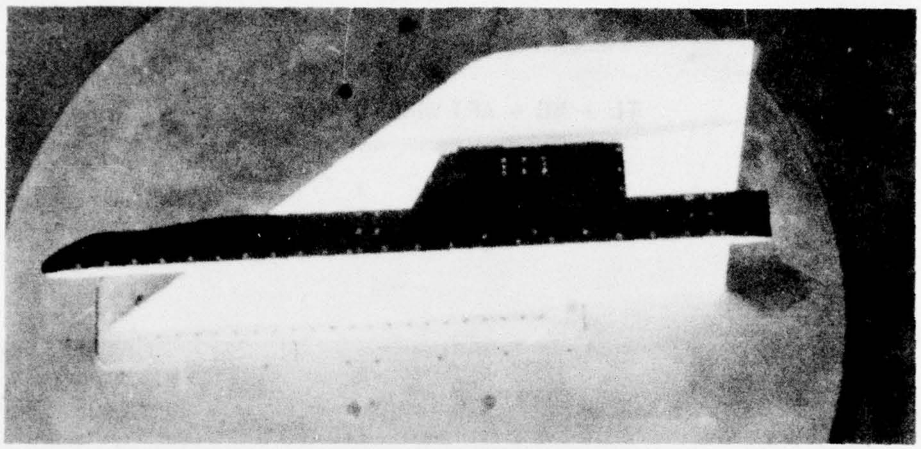


TL + MB + AW + CANARD FINS

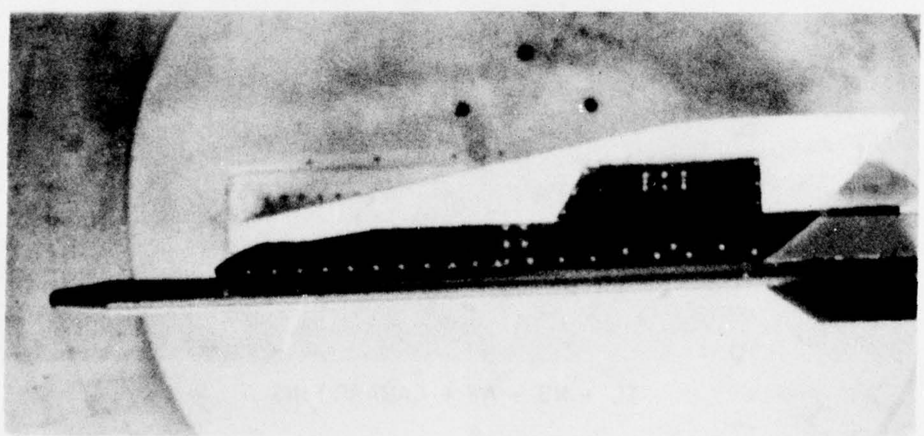
Fig. 6a Photographs of various tip store configurations (cont'd)



PYLON (P)



P + LAUNCHER (L)



P + L + MISSILE BODY + AFT WINGS

Fig. 6b Photographs of various under-wing store configurations

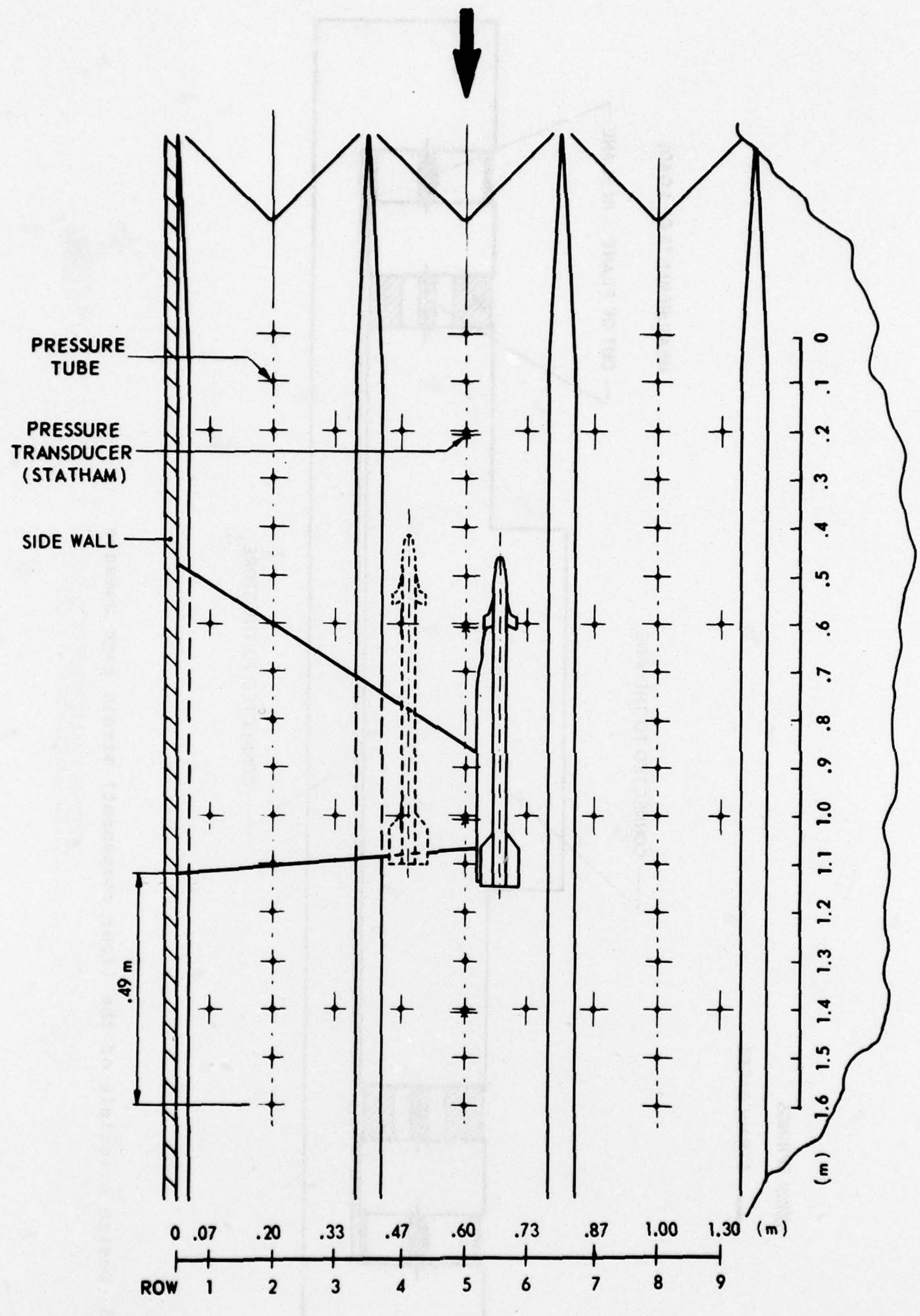


Fig. 7 Location of pressure orifices mounted in the top wall of the test section

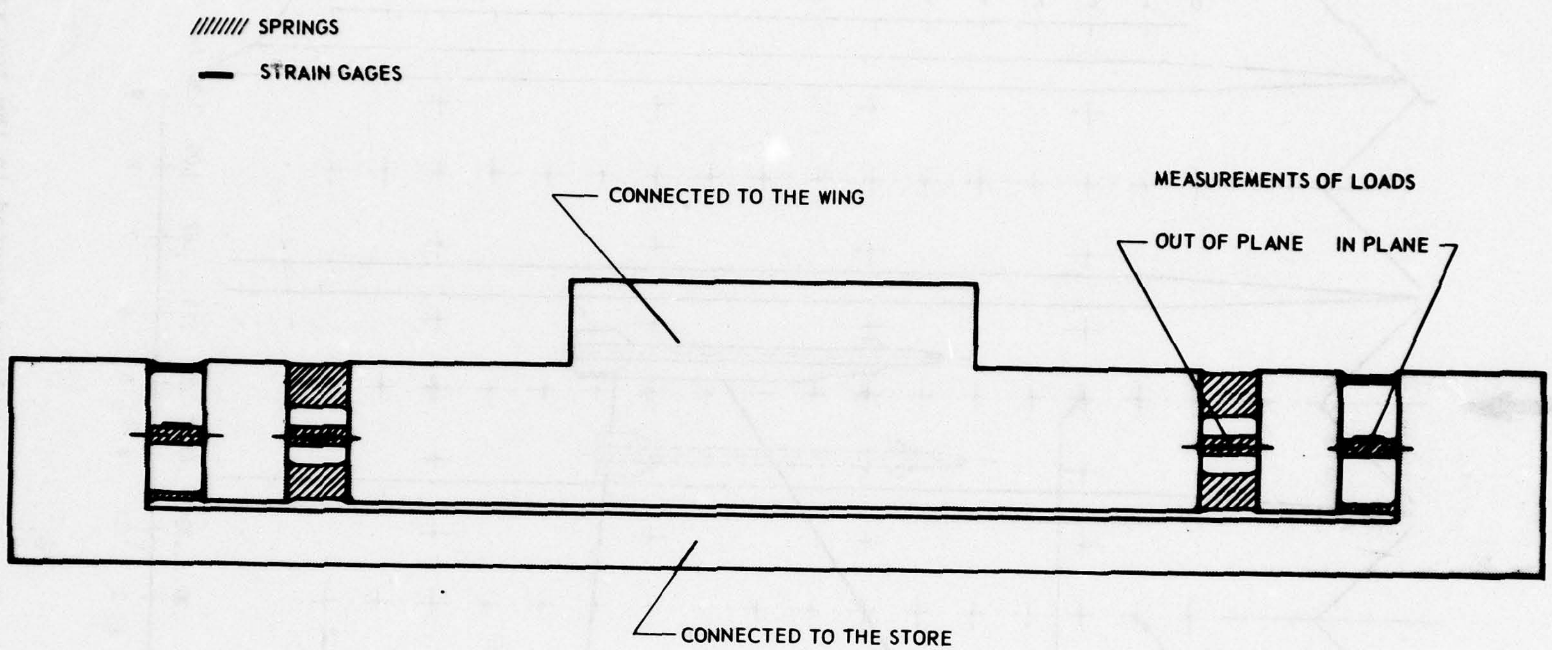
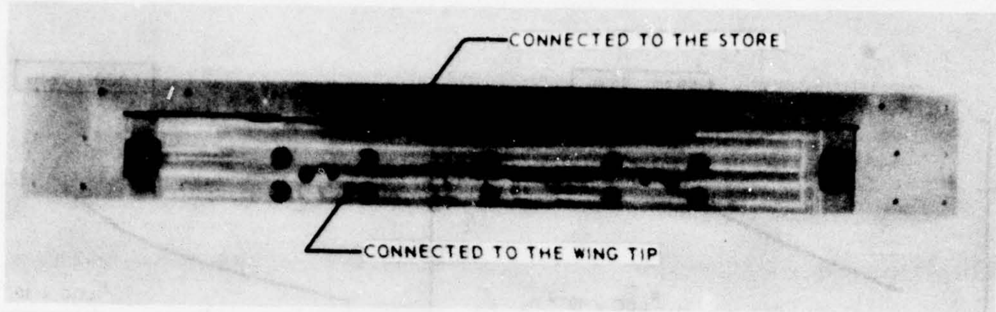
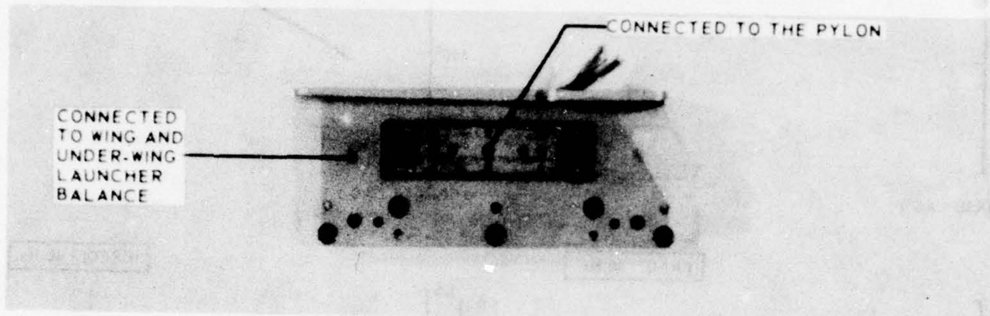


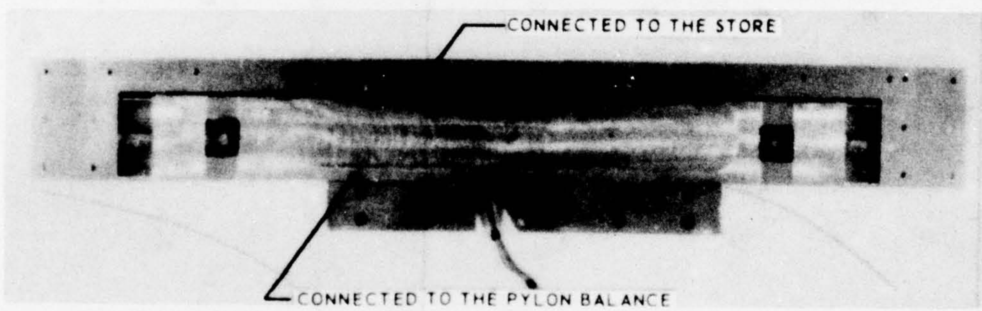
Fig. 8 Design principle of the (four component) strain gage balance



TIP LAUNCHER BALANCE



PYLON BALANCE



UNDER-WING LAUNCHER BALANCE

Fig. 9 Photographs of strain gage balances

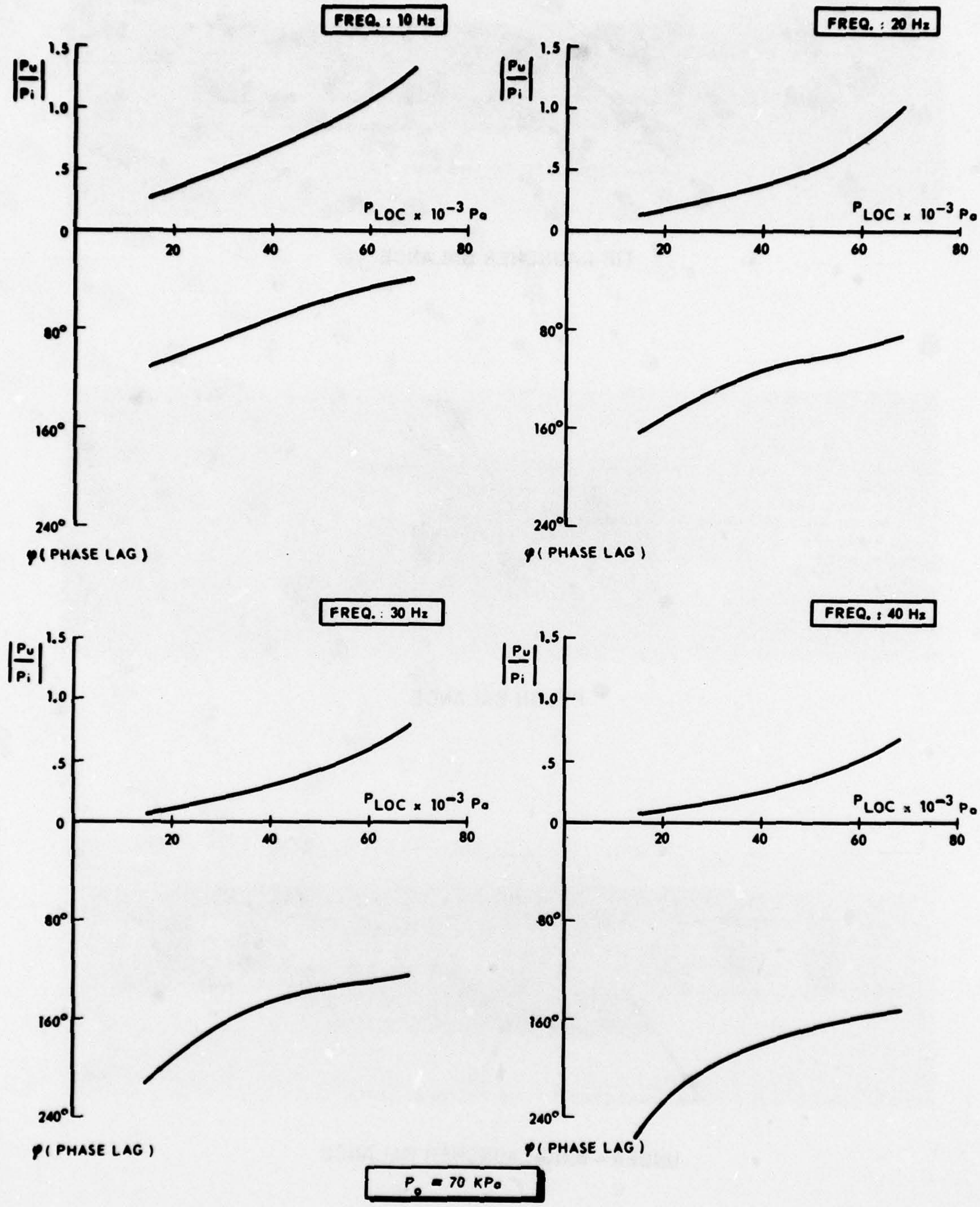


Fig. 10 Transfer functions used for data reduction of the unsteady pressures

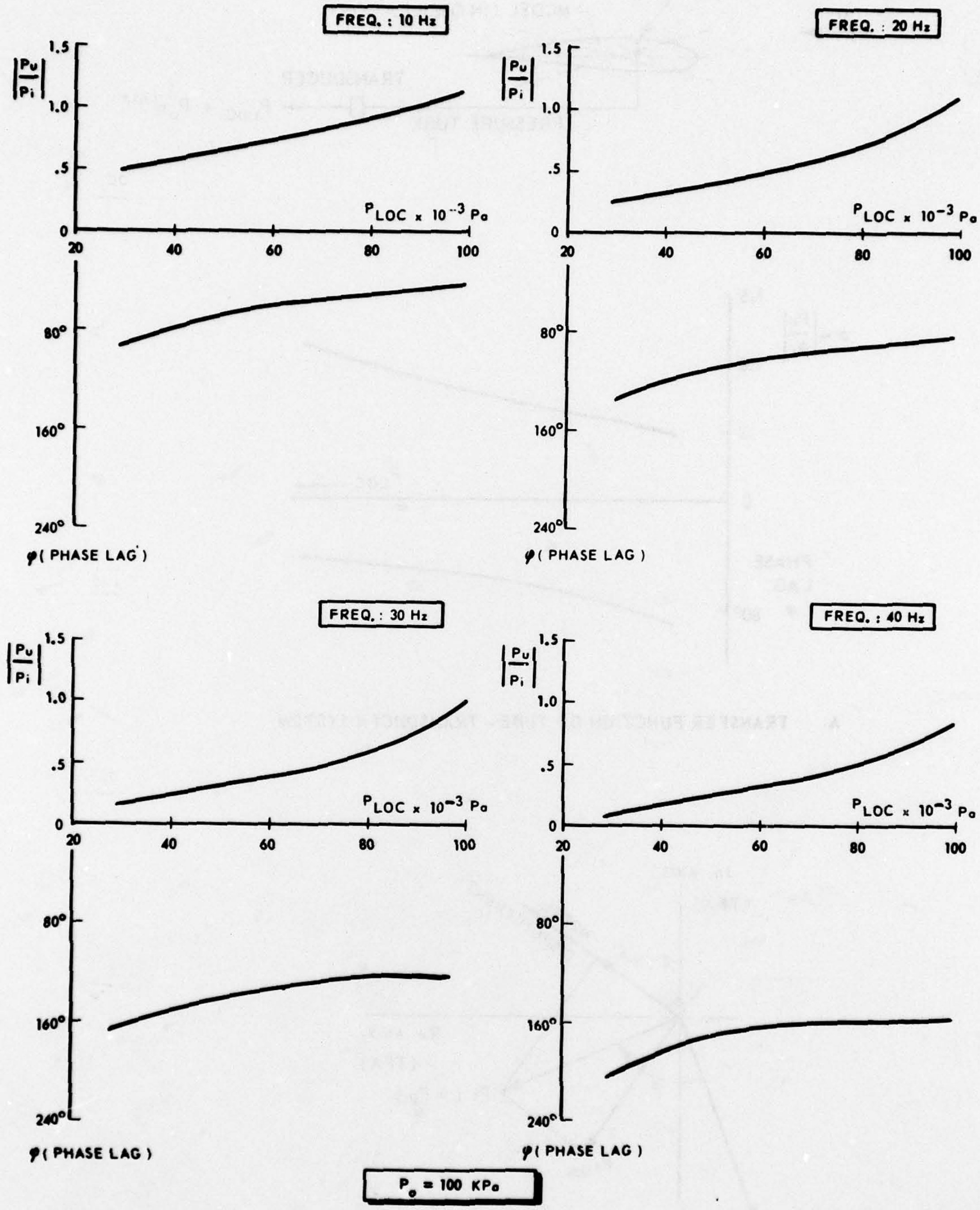
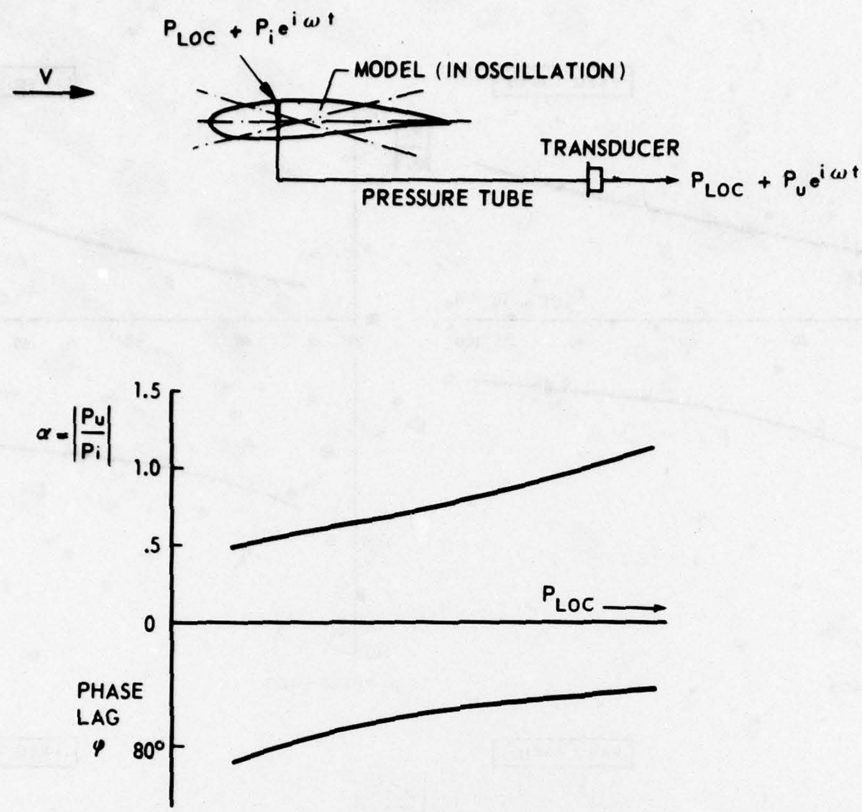
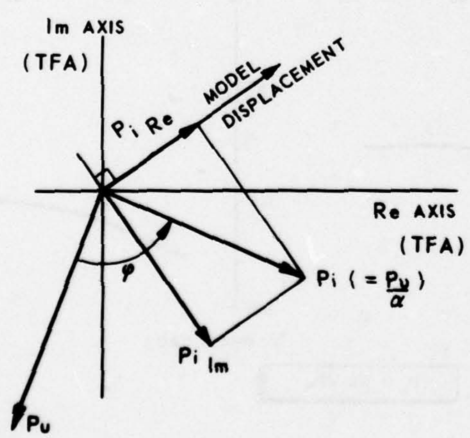


Fig. 10 Transfer functions used for data reduction of the unsteady pressures (cont'd)

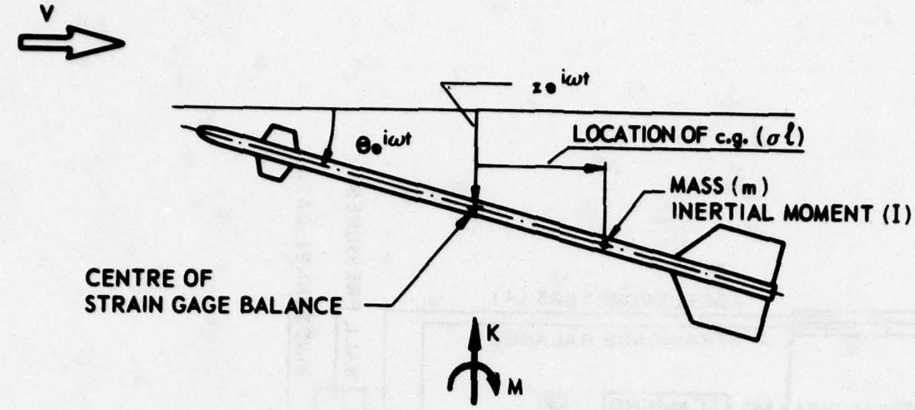


A TRANSFER FUNCTION OF TUBE – TRANSDUCER SYSTEM



B DATA REDUCTION PROCEDURE

Fig. 11 Principle of unsteady pressure measuring technique



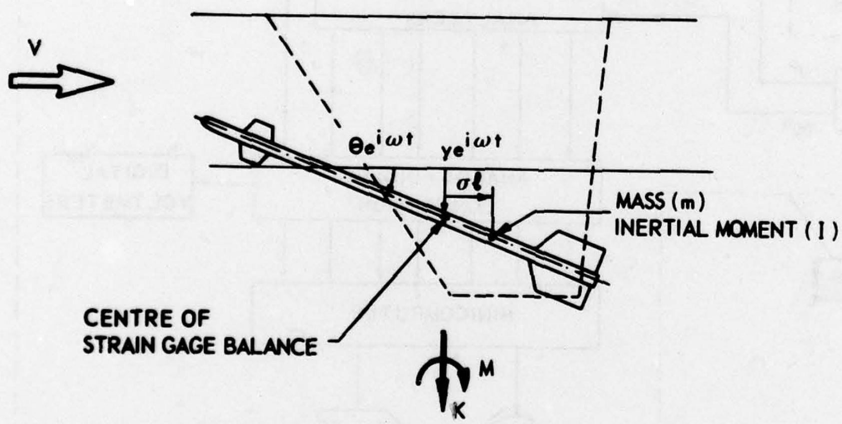
(1) INERTIAL LOADS: $K^* = m(\ddot{z} + \ddot{\theta}\sigma\ell)$

$M^* = -I\ddot{\theta} - m(\ddot{z} + \ddot{\theta}\sigma\ell)\sigma\ell$

$\ddot{z}$ AND $\ddot{\theta}$: ACCELERATIONS OF AND AROUND BALANCE CENTRE

(2) AERODYNAMIC LOADS: $K_{AERO} = K_{TOTAL} - m(\ddot{z} + \ddot{\theta}\sigma\ell)$ (NORMAL FORCE)

$M_{AERO} = M_{TOTAL} + I\ddot{\theta} + m(\ddot{z} + \ddot{\theta}\sigma\ell)\sigma\ell$ (PITCHING MOMENT)



(3) INERTIAL LOADS: $K^* = -m(\ddot{y} + \ddot{\theta}\sigma\ell)$

$M^* = -I\ddot{\theta} - m(\ddot{y} + \ddot{\theta}\sigma\ell)\sigma\ell$

$\ddot{z}$ AND $\ddot{\theta}$: ACCELERATIONS OF AND AROUND BALANCE CENTRE

(4) AERODYNAMIC LOADS: $K_{AERO} = K_{TOTAL} + m(\ddot{y} + \ddot{\theta}\sigma\ell)$ (SIDE FORCE)

$M_{AERO} = M_{TOTAL} + I\ddot{\theta} + m(\ddot{y} + \ddot{\theta}\sigma\ell)\sigma\ell$ (YAWING MOMENT)

Fig. 12 Principle of determining unsteady aerodynamic loads

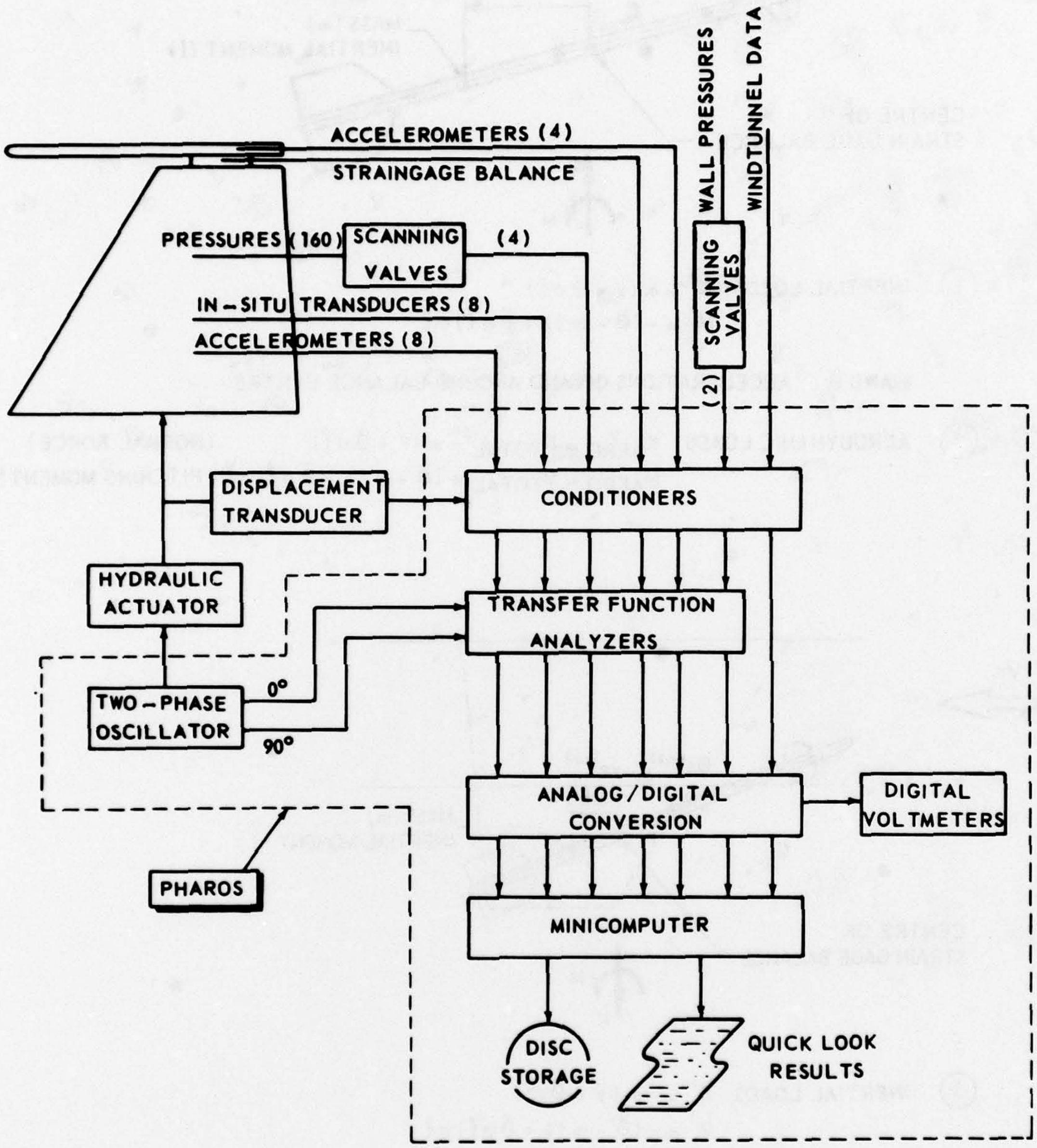


Fig. 13 Block diagram of the test set up during unsteady measurements

*U.S.Government Printing Office: 1979 — 657-002/482